RESPONSE TO FCC 98-208 NOTICE OF INQUIRY IN THE MATTER OF REVISION OF PART 15 OF THE COMMISSION'S RULES REGARDING ULTRA WIDE BAND SYSTEMS

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Summary

Radar is now extensively used for the measurement of liquid levels in big tanks for oil and other potentially hazardous products. Most commercial products for radar level gauging (RLGs) are operating under FCC part 15. The technical background is discussed below together with possible implications of spread spectrum or UWB technology together with proposed changes of the part 15 rules. For the possibility to apply this reliable and well accepted method to more environmentally critical application it would be very beneficial to make a rewriting of the part 15 rules to apply it to newer systems while maintaining its level of interference protection. The same changes of part 15 would apply to other applications as well and the discussions below could be extended.

Application background

Measuring of liquid levels by microwaves (radar) started commercially 1976 on tanker ships and 1984 on big tanks in refineries and storage plants. From the beginning it was an expensive method compared to older methods but in spite of that the acceptance among the users grew fast. The technique is now mature and quite cost effective due to low cost microwave semiconductors from satellite TV, good microprocessors and other developments in the field of process control. The market has grown quite a lot and now 2/3 of all big tanker ships are equipped with radar level gauging while a considerable part of new storage tanks on refineries, chemical plants etc also are equipped with radar level gauges. Close to 120000 units are now installed worldwide mainly for high duty applications and around 20 manufacturers are on the market. The main reasons for the fast marine acceptance in spite of the high price was the high reliability which became very important in the mid seventies due to increasing environmental and safety concern. The acceptance of the radar method for level gauging is now firm and on industrial tanks high reliability and accuracy are also the main reasons. In the past a number of disasters due to overfilling tanks etc have occurred when level gauges have given the wrong reading or being mechanically stuck.

Basic radar methods used for RLGs
Most RLGs for high accuracy use wideband Frequency Modulated Continuous Wave (FMCW) with different kinds of modulation and with a carrier of typically 10 GHz. When Part 15 rules are applied to these FMCW-systems they can be regarded as UWB-systems having a relative bandwidth of 10-15%. Other RLGs use pulsed systems of different kinds but still with typical UWB spectrum characteristics having 15% or more relative bandwidth. The more accurate of the pulse type systems use a pulsed carrier (such as 5.8 GHz) while the low cost RLGs generally use a “DC pulse” having a spectrum from some 100 MHz to some GHz. More data for the different systems will be discussed later on.

Microwave emission
It has been a strong market demand to extend the use of the radar method to more level gauging applications. One potential problem is that the requirements for accuracy, reliability and installation versatility implies that a quite wide band within a fairly limited frequency range must be used implying some problem when a system is designed to fall within existing emission regulation. For the present applications for FMCW RLGs a low power (0.1-1 mW for various manufacturer) is used within a closed metallic tank which gives a radiation outside of the tank which is far below the limits for FCC part 15. In many cases (such as plastic tanks and applications in open water reservoirs etc) the reliability and environmental benefits of the method can not be utilized for the time being due to possible radar emission above the part 15 rules when there is no metallic tank shell as a screen. The suggestions for changing of the formulation of the part 15 rules contain important possibilities for an extended use without increasing the interference if suitable signal characteristics and signal processing are used. Some estimations for possible disturbance levels are done below after having discussed the technical requirements for the liquid level gauging by radar.

Technical background.
Four conditions are the most important for the choice of system concept for a radar level gauge as based on pure technical issues:

A. Most tanks level gauges in refineries and tank farms are installed as retrofit on tanks containing oil etc. Thus no “hot work” (welding etc.) can be done so the tank structure, location and size of mounting holes etc. must be used as they are. Obviously the existing tank structures are not intended and many times barely suited for RLG installations. Typically that means that a narrow antenna beam (a few degrees) has to be used to avoid disturbing echoes and that a hole of typically 8” has to be used to locate the antenna.

B. Choice of carrier frequency. Due to various requirements there is a rather narrow range which will give acceptable performance for a radar level gauge. To produce a narrow antenna beam within a limited antenna diameter (to be installed through a small hole) a high frequency should be used. Due to the physical properties of water, oil and other substances adhering to the antenna a low frequency should be used to avoid the attenuation of substances adhering to the antenna due to condensation etc. This attenuation expressed in dB/mm will increase sharply with the frequency also depending on the attenuation peak for water at 22 GHz. Most radar level gauges use a frequency in the order of 10 GHz with some at 5.8 GHz. For radar level gauges using some kind of transmission line lower frequencies may be possible to use. The use of lower frequency can apply both to FMCW and pulsed systems. Some systems use pulses without a carrier (UWB=Ultra Wide Band signals) resulting in radiation over a wide frequency range from some 100 MHz to some GHz. The transmission line is generally open (like two parallel conductors) to prevent contamination and the open line do have some radiation from the line. The transmission line does not utilize the non-intrusion benefit of radar but sometimes the free space required for the radar beam can not be found. Systems using a transmission line many times use a DC pulse of 1-2 ns and their content of low frequencies is useful for this special application. The transmission line is sensitive to contamination but the low frequencies will have less attenuation preserving some function at reduced accuracy while the higher frequencies are attenuated away by the contamination.

C. The bandwidth must be in the order of 1 GHz or bigger. The radar resolution in terms of distance is closely related to the bandwidth and to get required measuring performance echoes one to a few hundred mm or less apart must be resolved. Systems using swept frequency (FMCW) are used as well as pulsed system. The pulse width in the last case is typically 1 ns which (depending on the pulse shape) corresponds to at least 1 GHz. FMCW systems obviously give much better bandwidth definition than pulsed systems with the same distance resolution. The restricted bands are easily avoided by FMCW-systems and pulsed systems using a carrier while it is less obvious how to avoid a DC-pulse to interfere with broadcasting band etc without using complicated filters. On the other hand typical for this UWB-systems are that only low spectral densities are radiated.

D. Accuracy is important with the typical requirement being 2 mm over 20 m or 0.01% which also can be expressed in time as 13 pico seconds. This is a crucial background to the choice of system concept and for the very high accuracy systems (allowed for custody transfer) only FMCW-system have been used. Many applications for radar level gauging with moderate accuracy requirements are primly utilizing the ability to stand difficult environments inherent in a non intrusion method with and then pulse type system have also been useful.

20 GHz is a coarse upper limit set by attenuation in layers on the antenna built up by oil, moisture etc. Below that frequency no 1 GHz bandwidth exists which is not already in use. By using a low power (<1 mW) and enclosing the gauge in a metallic tank the radiation outside of the tank will be below the part 15 limits which is used by the high accuracy level gauges of FMCW-type on the market. Pulsed systems typically have 1-10 mW peak power but a very low duty cycle (0.01-1%) which can make the average radiation in 1 MHz bandwidth below the part 15 limits even without a metallic tank shell. Peak radiation over a wider band may on the other hand be more than 20 dB over average level.

By different modulations the modulated signal (FMCW) can have noise-like characteristics and be restricted to a limited band analogue to spread spectrum communication devices. Pulse-type level gauges may have random pulse repetition rate giving a spectrum without peaks at multiples of the PRF. If a sufficiently noise like modulation is used (analogue to “spread spectrum”) then the radiation from a radar gauge can in both characteristics and level be comparable to the thermal radiation from the tank itself within the same frequency range.

Estimations of noise levels

The amount of noise modulated radiation should be compared to the natural thermal noise. The surface of the ground will radiate $8\pi kT\Delta f/\lambda^2$ watt per square meter (Planck's radiation for a "black body") which for 1 GHz bandwidth and λ=0.03 m (10 GHz) is 100 nW per square meter at normal temperature (15°C). For l=0.1 m (3 GHz) the noise will be 10 dB lower (10 nW per square meter) and for 1 GHz further 10 dB lower (1 nW per square meter). For a typical outdoor refinery tank the area occupied by the tank and its most near surroundings is 1000-10000 m^2 and from 1000 m^2 the radiated thermal power within 1 GHz bandwidth around 10 GHz will be 0.1 mW. Thus the thermal noise within the same bandwidth will generally be comparable or even higher than the detectable signal from the radar level gauge supposing the signal is modulated in a suitable way and the output power is kept below a certain limit such as <0.1 mW. The comparison between thermal noise from the near surroundings and the stray radiation from the radar level gauge is relevant very close to the tank (<one tank diameter away). Far away where the tank (or area covered by tanks) is smaller than the area covered by the receiving antenna the thermal noise will be stronger as seen by an antenna on some other system. This values can be compared with the present limits 0.5 mV/m (which is 0.66 nW/m^2) average at 3 m measured over a bandwidth up to 1 MHz. If the radiation in that case should be isotropic this corresponds to 75 nW over 1 MHz or 0.075 mW over 1 GHz. The results are comparable for the 10 GHz case so a limit based on the spectral density of the thermal noise in the real environment should not give results far from present FCC part 15 test procedures. A pulsed system will spread the power by using short pulses and assuming a random pulse rate is used the spectral density may be low in spite of a rather high peak power. If for instance 10 mW peak power and 0.1% duty cycle is used then the spectral density will be 0.01 mW over 1 GHz. The peak power for a pulsed system might be more than 20 dB over the average and will also require a very fast spectrum analyzer or a sampling oscilloscope to be measured.

Possible disturbances and discussion of formulation of limits

The following matrix can be formulated to discuss disturbing possibilities:

Source of disturbance below:	Narrow band system possibly disturbed	Broad band system possibly disturbed	Restricted bands
Narrow band type	Present amplitude limit does not always protect, as narrow band systems may be very sensitive.	Typically broadband systems are designed to withstand narrow band signals as well as various kinds of noise-like signals.	Easily avoided
Wide band noise like signal usually created by FM or AM modulation of a carrier	At sufficient distance the radiation will give no problems if spectral density at that distance is below the thermal noise.	Spectral density sets the limit and if the received disturbance is below the thermal noise little disturbance will occur.	Can be avoided with suitable choice of modulation but without complex hardware
Pulse train with a carrier	If random repetition rate is used and no saturation occurs disturbance will be based on spectral density	If no saturation occurs disturbance will be based on spectral density	Can be avoided with suitable choice of modulation but without complex hardware
Pulse train without carrier (“DC pulse)	If random repetition rate is used and no saturation occurs disturbance will be based on spectral density	If no saturation occurs disturbance will be based on spectral density	Generally filters must be used to avoid emission within restricted bands.

A very crude sketch of test ideas can now be proposed where present values are kept but understood as spectral power densities for bandwidths over 1 MHz. Any bandwidth and frequency should be applied for the test. A restriction to avoid certain bands can easily be implemented by FMCW-systems or by a pulse-modulated carrier but systems using DC-pulses have to apply filters, which probably will be too complicated for simple systems. The high amplitude of certain pulsed systems obviously may present a problem, which however can be solved by limiting the broadband peak power. The crude sketch of the proposed test then can be formulated as:

> The radiation is measured with the present limits (0.5 mV/m at 3 m) at 1 MHz bandwidth corresponding to 0.66 nW/m^2 field intensity.

At wider bandwidths (up to several GHz) the spectral density (0.66 nW/m^2MHz) is used. At X MHz bandwidth X times higher power should be allowed.

At a more narrow bandwidth the best protection will be obtained if the same spectral density is used as at 1 MHz (that is lower power at lower bandwidth) but otherwise present limit can be preserved if they are found acceptable. Very narrow band systems are not well protected by present limits.

The limit implies that the signals will be comparable to natural thermal noise at 10 GHz. With thermal noise as a standard the limits should be lower at lower carrier frequencies and higher at higher. This also applies to harmonics.

This very crude sketch illustrates that for carriers around 10 GHz and at higher frequencies the present levels (0.5 mV/m at 3 m distance) understood as spectral density (0.66 nW/m^2MHz) will give good protection for interference from suitable modulated wideband signals as they will have a level comparable to thermal noise. Far below 10 GHz the present levels may be seen as too high (depending on existing experience on the present levels) and for narrowband systems disturbed by narrow band signals the present levels do not give a formally good protection.

From a more theoretical point both amplitude and spectral density should be limited and tested at different bandwidths over the frequency range. Independent of the type of modulation the emission then can be limited to be below the thermal noise at a certain distance.

Answers to the questions with emphasis on RLG applications:

9A: FMCW with various modulations such as sweep plus spectrum spreading modulation etc., pulse with carrier and pulse without a carrier.

9B: Bandwidths around 1 GHz and up. Frequencies 1-25 GHz. ISM-bands are too narrow or at too high frequencies to allow for general operation as RLG.

9C Average power levels can for different applications be 0.001 to 1 mW. For FMCW systems peak value is the same while pulsed systems may have 0.1-10 mW peak value. Spectral density outside of the device under test (3 m away if it is small) below 0.075 mW/GHz. The tank is generally considered as a part of the device under test.

9D 0-65 m within the tank.

10A Some are operated under part 90

10B A system using a fairly smooth frequency spectrum with a width from 5% of centerfrequency and up. Typical problem in this cases is that low power and noise-like spectrum must be used to avoid interference as no “free” wide band exists allowing operation

11A With present foreseen use it is likely that the restricted bands will not be disturbed but as a precaution it seems wise to keep the restricted bands restricted. Assuming no problems occur at other frequencies the restricted bands can be considered later on when there is a wide experience. Present formulations of the part 15 limits seem high among the TV bands as compared to other noise.

11B. If a change adopted to UWB should be made still precautions should be made to protect TV, mobile telephone bands, GPS etc. The rationals discussed above based on thermal noise also suggests lower limits for lower frequencies.

11C System based on DC pulses have difficulties in controlling spectral occupancy and may have to use lower powers. Some of the cases probably have to be excluded but many will remain.

12A From a theoretical standpoint they are too high at low frequencies (say 1 GHz) but too high at frequencies above 10 GHz (i.e. much higher than thermal noise). From the same very simplified theory field strength limit should be proportional to frequency. No opinion based on practical experience other than mobile phones where licensed radiation causes problem by unlinear effects.

12B The same limits should if possible be applied to all kinds of signals but they should be formulated to cover all cases which the present rules are not. Wide signals generally are less able to disturbed than narrow band ones having the same power at sensitive frequencies. High powers causing unlinearities is another difficult case. For wide band signals spectral density is the right measure. The least probability of interference should occur when the signals is smeared out in both frequency and time corresponding to a FMCW signal with a noise like modulation.

12C It is desired to have uniform rules to cover border cases. An approach to obtain similarities with broadband noise is good. From practical experience a signal can be quite far from mathematical white noise and still appear as noise in the receiving system. From the military side this subject is studied in depth.

12D Obviously an increased noise level will occur very close to a unit radiating a noise like signal. The comparison with the thermal radiation from the ground should be relevant and will give a measure of suitable maximum density. In the case of RLGs this is not a problem due to the rather high frequencies and low practical density of this units (i.e. the thermal noise will anyway be higher at a reasonable distance). On the other hand for a unit which you eventually will find dozens of in every home and which radiates below 1 GHz the density will call for rather low power levels if other appliance shouldn't be disturbed. As a comparison however present levels may give 30 dB over the thermal noise below 1 GHz.

12E Yes. Probably in the order of 1 mW but possibly frequency dependent.

12F For systems using DC-pulses this is generally necessary but the antenna may be that filter. Other systems should not need a special filter, as the transmitter anyway will limit the spectrum.

12G Yes. This is nothing special for UWB systems. Some type of mains filtering will generally be required to take away microprocessor clock frequencies etc.

12H Generally not except for restricted bands. At low frequencies (<1GHz) the probability of disturbance clearly exists so units likely to be used in high density (several in each home) should probably have restricted power.

12I. Yes. Practical broadband systems (commercial, industrial and military) are designed to stand a general noise-like disturbance. Some kind of condition to ensure that the power is sufficiently smeared out in frequency as well as in time should be applied. Systems using very low power obviously can have less restriction in this respect.

13A No opinion

13B Yes. It should be a goal to use the same limitations for all signals. A limit on power as well as spectral density should be formulated.

13C With a formulation in spectral density the “carrier” will be of less interest. The spectral density limit will still have to be different for very different frequencies.

13D. Most measurements should be possible to carry out by a spectrum analyzer but a wider bandwidth than the typical analyzer has today is useful. Furthermore a combined measurement of spectral density and amplitude should probably be used.

13E Yes. The requirement to switch off any frequency sweep (if present) seems to be irrelevant in the case of a FMCW-radar. The wide band system may have several types of modulations and there seems to be little use of treating the sweep separately. When omitting this requirement some other requirement applying to whole the signal probably has to be introduced. Furthermore for those RLGs designed to operate in a closed tank only the measurement should be done in such a tank. This tank is probably small which is a more severe case than a big tank where most radiation will be absorbed inside before it hits any possible joint.

14A The concept of damped waves is obsolete and if such a device should appear (escaped from a museum?) it would anyway be rejected unless the power is very low.

14B Comparison with a standardized value atmospheric and thermal noise should be a practical way to determine acceptable limits and to determine the cumulative effects of many transmitters. For low frequencies (say < 1GHz) this will give very low levels compared to present limits and a judgement based on practical experience have to be done.

Conclusions

By using a formulation based on spectral density and coinciding with the present limit at 1 MHz both narrow band and wide band receivers will get sufficient protection from interference caused by radiators geographically spread like radar level gauges. The main support for the protection is that the disturbance will be lower than the thermal noise when hitting the unit which is thought to be disturbed. This applies to rather high frequencies like 10 GHz while lower frequencies and narrow bandwidth using present limits do not guarantee freedom from interference from narrow band transmitters to narrow band sensitive receivers.

About the author

Olle Edvardsson received his MSEE 1965 at KTH in Stockholm, Sweden. From 1966 employed at SAAB Aerospace for military radar development and since 1970 occupied with radar level gauging. Also 15 years work with military radar systems including electronic warfare questions and 3 years in mobile telephone system and antennas. 11 patents in radar level gauging, antennas and radio identification systems.